The numerical results we have generated show that the transmission properties of the bend are significantly improved with a miter cut at the corner. By themselves, our results provide an accuracy check for the more sophisticated integral equation approach which can handle arbitrarily shaped boundaries. Moreover, with a slight modification, this technique may be extended to study microstrip corners with an arbitrary miter.

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The Use of a Single Source to Drive a Binary Peak Power Multiplier

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***Abstract*—The binary power multiplier (BPM) recently proposed by Farkas [1] requires a pair of RF inputs whose phases are set independently. In this note, a method is presented in which a single source may be used to drive a BPM. Phase coding occurs at the source input, where the power is low and phase switching is straightforward. There is a loss in energy of around 25 percent but only a small reduction in peak power.**

I. Introduction

Future TeV linear colliders require sources producing peak power in the 100 MW range. The exact power level depends on frequency, but present estimates are around 750 MW at 2.8 GHz [1] (SLAC frequency), 500 MW at 10 GHz [2], and 200 MW at 17 GHz [3]. When additional constraints such as high efficiency, high gain, and phase stability are introduced. these powers are beyond the state of the art of present and near-future sources. To circumvent the lack of suitable sources, pulse compression may be used to increase peak power at the expense of pulse length, thus reducing the requirements to technologically feasible levels.

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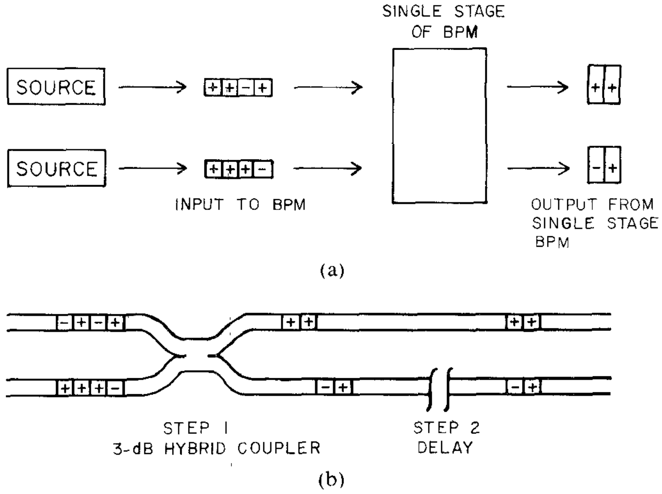

Fig 1. (a) Coding for a single-stage binary power multiplier The time bins are coded according to phase· − represents 0° and + represents 180°. On output, the pulse length is halved and the power doubled (b) Schematic of a single-stage BPM.

Recently, Farkas proposed an efficient multiple-stage pulse compression scheme [1] in which the power is doubled and the pulse length halved at each stage. The scheme is described in detail in [1]. Briefly, a single stage of the binary power multiplier (BPM) works as follows: the input into each stage consists of two pulse trains coded into time bins, with a phase of either 0° or 180° in each bin. The pulse trains are combined to produce two outputs, each at twice the power and half the duration and properly coded for the next stage. The coding for this process is illustrated schematically in Fig. 1(a), where a phase of 0° is denoted by a − and a phase of 180° by a +. The power doubling, which is shown in Fig. 1(b), occurs in two steps. First, adjacent bins are combined by a 3 dB hybrid coupler according to the rules given in [1]. Second, the leading pulse is delayed so that the bins are again adjacent. The peak power multiplication is 2^n for an n-stage device, less any losses due to nonideal properties.

This pulse compression scheme has been demonstrated at low power using both fundamental mode rectangular and TE_{01} circular waveguide [3]. While the basic validity of the binary pulse multiplication scheme was confirmed, the losses were high (greater than 40 percent power loss for the two-stage BPM). For practical applications, delay lines with acceptable wall losses and 3 dB hybrid couplers with minimal mode conversion and reflection need to be designed. In addition, problems of phase noise need to be studied, as the BPM efficiency degrades rapidly with phase jitter.

Because of the high power involved, the coding of the pair of pulses trains which enters the BPM must occur at the input end of the source, where the power is low. Consequently, two separate sources are needed to drive a single BPM if it is to operate at maximum efficiency. For testing and development, however, it is desirable to use a single source. This may be done with some decrease in energy efficiency (less than 30 percent) but little loss

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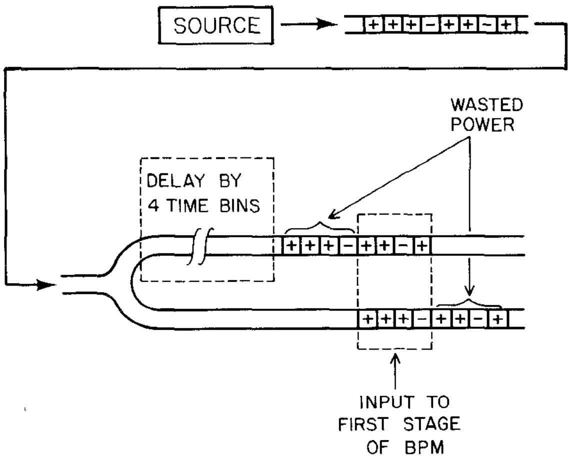

Fig. 2. Preparation of a single source for input into a three-stage BPM. Note that the overlap region has the same coding as in Fig. 1(a). This method works for any number of stages, as the first and second half of a pulse may be coded independently.

in peak power. A description of the single-source BPM is presented in the next section, and a summary is given in Section III.

II. A Single-Source BPM

To function, a BPM requires only a pair of pulse trains with the proper coding. While in principle one could split the output from a single source and code each independently by introducing a 180° phase shift at appropriate times, the high powers involved preclude such an approach. However, a single source may be used with 50 percent loss in energy by coding the input into twice as many time bins as are needed, splitting the output, delaying one of the pulse trains by half the pulse length, then recombining the first half of one pulse with the second half of the other. This process is illustrated in Fig. 2 for a two-stage, single-source BPM. The final pulse is 1/8th the length of the source output and four times the power. While half the energy is wasted, there is only a small loss in peak power that occurs during the initial splitting and delay.

In fact, with a proper design it is possible to use significantly more than 50 percent of the pulse. For instance, by splitting a five-bin output in two and combining the first 80 percent of one with the last 80 percent of the other, proper coding for a $\times 4$ BPM can be achieved (see Fig. 3(a)). This is possible even though the combined pulse trains are not independent, essentially because the coding for a BPM is not unique—there are many "correct" initial coding sequences for a given multiplication factor. Thus, while there is no guarantee of finding an energy efficient device for multiplication above $\times 4$, we except at least some improvement over 50 percent.

Using a semisystematic trial and error method in which successively longer delays (and thus lower efficiencies) were investigated, improved intrinsic efficiencies were found for $\times 8$ and $\times 16$ BPM's. The details of this method may be found in the Appendix, and the resulting codings are shown in Fig. 3(b) and 3(c). Note that the efficiencies are now 73 percent (8/11) and 76 percent (16/21), a substantial increase over 50 percent. It is expected that similar results would be achieved at higher multiplication factors.

While the increase in energy efficiency is an added plus, the main thrust here is that a BPM can be driven with a single source. This will significantly lower the cost, both economically and in terms of manpower, of testing and development of BPM's

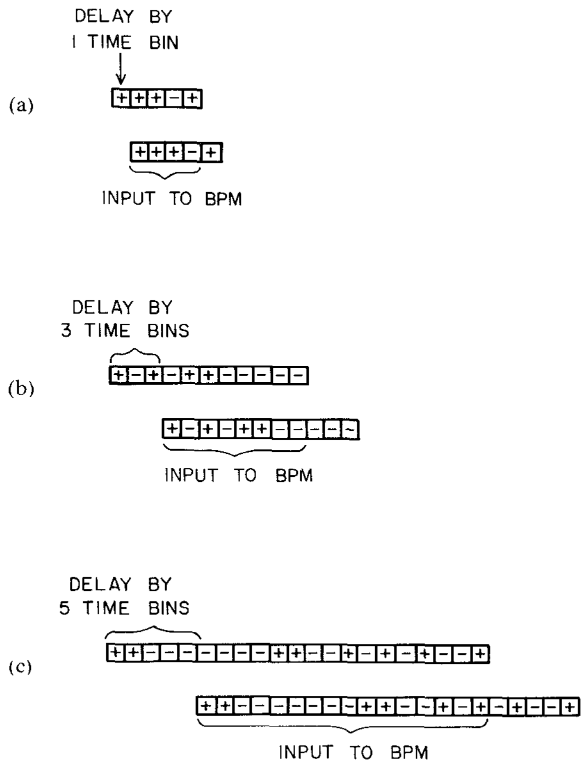

Fig. 3 Energy efficient coding for a single source: (a) $\times 4$ multiplication; (b) $\times 8$ multiplication; (c) $\times 16$ multiplication.

for practical applications. In addition, even with a 30 percent energy loss the single-source BPM is only slightly less efficient than SLED [4], the pulse compression scheme currently in use at the Stanford linear accelerator. Moreover, it can produce larger compression ratios (SLED efficiency peaks at about 3:1) and a significantly flatter output pulse [1]. Thus, in applications where efficiency is not at a premium the relative simplicity of a single-source BPM makes it an attractive alternative to the two-source BPM.

III. Summary

A method is illustrated for driving a BPM using a single source. As with the two-source BPM, coding occurs at the source input where the power is low. While there is an additional loss of energy between 20 percent and 30 percent over a two-source BPM for $\times 4$, $\times 8$, and $\times 16$ multiplication, there is only a small reduction in power associated with the initial splitting and delay of the source output.

Appendix
Energy-Efficient Coding

Because there are 2^{2^n} different possible codes in an n-stage device, finding the coding for an energy-efficient BPM using a purely trial and error method would be prohibitively time consuming. However, the energy-efficient codes are special in that they arise from a shift: in an m-shift (for instance), there are $2^n + m$ bins and the last 2^n are aligned with the first 2^n to create the proper coding for an n-stage device. The resulting intrinsic efficiency is $2^n/(m+2^n)$. Fig. 3(a), (b), and (c) illustrates, respectively, a 1-shift, 3-shift and 5-shift. While the intrinsic efficiency depends only on the shift, to uniquely determine a coding sequence we need to specify both the shift and the number of bins that remain adjacent after the pulse has passed through each

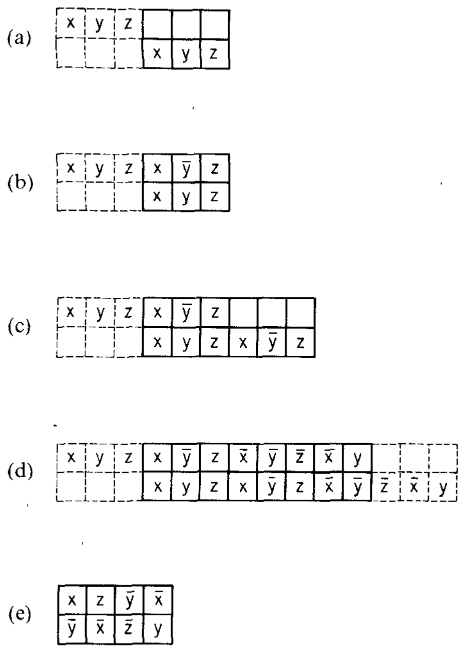

Fig. 4. Attempt at coding a $\times 8$ BPM with a 3-shift, 1-cycle (a) The first 6 bins (b) Addition of the triplet above (x, y, z); chosen to ensure a 1-cycle. (c) 3-shift of the triplet $(x, \bar{y}, z)$. (d) Symbolic coding of all 22 bins. (e) Coding after one stage of the BPM. No matter how x, y, and z are chosen, the appropriate coding for the next two stages of the BPM cannot be achieved.

stage of the BPM. As an example, consider Fig. 1(b). Referring to the number of adjacent bins as the cycle, we see that the coding in this figure produces a 2-cycle after the first stage and a 1-cycle after the second stage. Thus, Fig. 3(a), which has the same coding as Fig. 1(b), represents a 1-shift, (2,1)-cycle, Fig. 3(b) represents a 3-shift, (2,2,1)-cycle, and Fig. 3(c) a 5-shift, (2,2,2,1)-cycle.

While the full set of cycles is necessary to uniquely specify a coding, we are really interested only in the shift. A semisystematic trial and error method for finding the optimal coding can be stated as follows. Begin by choosing the smallest possible shift. Then guess a set of cycles and check whether or not it leads to a coding appropriate for a BPM. If not, increase the shift and repeat the process.

To demonstrate this method we construct the 3-shift coding for a $\times 8$ BPM. (We start with the 3-shift because shifts of 1 and 2 bins do not produce appropriate coding.) It is convenient to proceed symbolically. Let the $+$ and $-$ signs that previously represented phases of 0 and 180° be replaced by letters, and let a phase shift by 180° be denoted by an overbar. Thus, if x stands for $+$, then $\bar{x}$ stands for $-$, and $\bar{\bar{x}} = x$. Using this notation, the sequence in which we fill the 22 bins shown in Fig. 3(b) is presented in Figs. 4 and 5. Since we are using a 3-shift we can immediately fill in the first six bins (Fig. 4(a)). Let us guess that the first cycle is a 1-cycle so that the three bins above the triplet (x, y, z) are $(x, \bar{y}, z)$ (Fig. 4(b)). The new triplet $(x, \bar{y}, z)$ then shifts down to produce Fig. 4(c), and the triplet above it is $(\bar{x}, \bar{y}, \bar{z})$. Continuing the process, we fill in all 22 bins with symbolic phases (Fig. 4(d)).

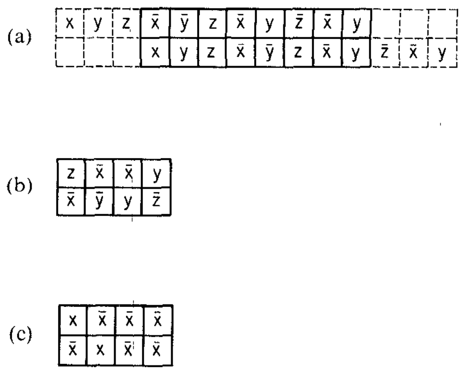

Fig 5. Coding of a $\times 8$ BPM with a 3-shift, 2-cycle. (a) Symbolic coding of all 22 bins. (b) Coding after one stage of the BPM. (c) Same as (b) except that y has been replaced by $\bar{x}$ and z by x. This coding is appropriate for the next two stages of the BPM.

The next step is to eliminate the nonoverlapping triplets at either end and pass the configuration through one stage of a BPM. This results in the coding illustrated in Fig. 4(e), and leaves us with four possibilities: $y = x$ or $\bar{x}$ and $z = x$ or $\bar{x}$. Unfortunately, none of these leads to the appropriate coding for a BPM, so we repeat the process with a 2-cycle instead of a 1-cycle. Following the above procedure, we arrive at the 3-shift, 2-cycle coding of Fig. 5(a); passing it through one stage of a BPM and eliminating the nonoverlapping triplets then produces the coding in Fig. 5(b). Finally, choosing $y = \bar{x}$ and $z = x$ yields the proper coding for a BPM (Fig. 5(c)), and letting $x = +$ recovers Fig. 3(b).

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